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LEARNING AND CREATIVITY WITH SPECIAL EMPHASIS ON SCIENCE.
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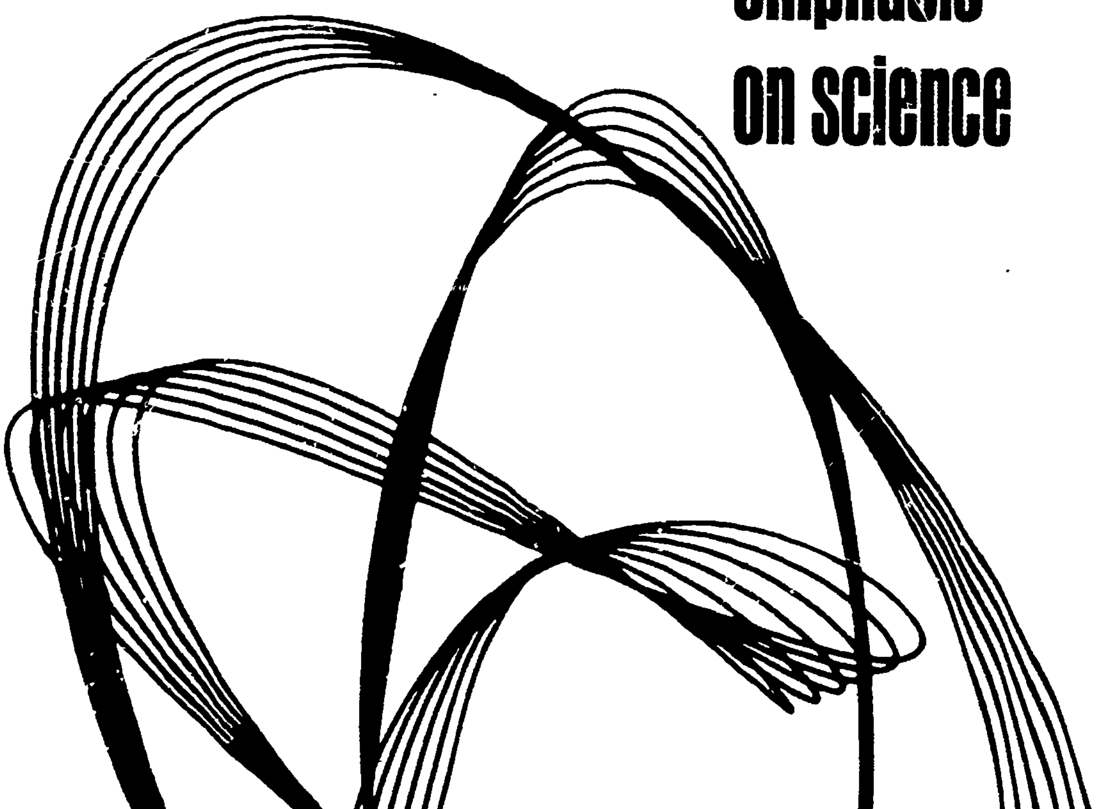
PAPERS CONCERNING (1) LEARNING AND METHODS OF INVESTIGATION, AND (2) CREATIVITY AND PRODUCTIVE THINKING ARE INCLUDED IN THIS NATIONAL SCIENCE TEACHERS ASSOCIATION PUBLICATION. IN THE PAPER THAT DEALS WITH LEARNING, A DEFINITION OF LEARNING AND A DESCRIPTION OF BEHAVIORAL PSYCHOLOGY ARE FOLLOWED BY A DISCUSSION OF DISCRIMINATIVE STIMULI AND RESPONSES IN THE MODIFICATION OF STUDENT BEHAVIOR. THE LANGUAGE OF SCIENCE, ITS METHODS OF INQUIRY, AND CONCEPTUAL SCHEMES ARE THEN RELATED TO STIMULUS-RESPONSE LEARNING THEORY. AFTER A BRIEF DISCUSSION OF INHIBITION, THE SOCIAL, PHYSICAL, AND INTELLECTUAL DEVELOPMENT OF THE CHILD IS CONSIDERED. CONCLUDING SECTIONS OFFER PRACTICAL ADVICE IN THE APPLICATION OF LEARNING THEORY TO CLASSROOM SITUATIONS. INTRODUCTORY SECTIONS OF THE PAPER ON CREATIVITY ARE DEVOTED TO THE NATURE OF THE CREATIVE PROCESS AND THE IDENTIFICATION OF CREATIVE TALENT IN THE CLASSROOM. MANY CHARACTERISTICS OF CREATIVE INDIVIDUALS ARE LISTED AND DISCUSSED. FOLLOWING A REVIEW OF RESEARCH STUDIES THAT HAVE IMPLICATIONS FOR SCIENCE TEACHING THAT ENCOURAGES AND FOSTERS CREATIVITY, SUGGESTIONS FOR THE IMPROVEMENT OF EXISTING SCIENCE EDUCATION PROGRAMS ARE MADE. FINALLY, A MODEL SCIENCE CURRICULUM WHICH RECOGNIZES THE STUDENT AS AN ACTIVE THINKER IS PROPOSED. THIS DOCUMENT IS ALSO AVAILABLE FOR $2.00 FROM NEA PUBLICATIONS SALES, 1201 SIXTEENTH STREET, N.W., WASHINGTON, D.C. 20036. (AG)

LEARNING and CREATIVITY

with special emphasis on science



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National Science Teachers Association

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National Science Teachers Association

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FOREWORD

INQUIRY, individualized instruction, and independent study are the order of the day in educational philosophy. This is especially true in science where these characteristics are at the very heart of the subject. To transform these concepts from the philosophical to the operational in teaching as well as in learning requires not only courage and stamina, compassion and insight, but a new competence in guiding and a new generosity in releasing the young spirit to its own ideas. Those who learn, as well as those who teach, face a new terrain. For each to find his own path, the terrain must be charted and the traveler's skill appraised. For the first, we look to the theories of learning. For the second, it is creativity that we hope to identify and to foster. Therefore, in this publication we present a section on "Learning and the Methods of Investigation" and one on "Creativity and Productive Thinking in Science Education." These companion monographs grew out of the work of an Association committee on new approaches to science education for the junior high school level, but they are applicable to education at all levels and in other subject areas as well as in science. We hope that these discussions will indeed help to transform philosophy into practice so that teachers will become better guides and students better travelers in an increasingly open educational journey.

Robert H. Carleton
Executive Secretary
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LEARNING

and methods of investigation

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ANALYSIS of conceptual structures that describe and explain physical and biological phenomena is the task of physical and biological scientists. Analysis of conceptual structures that describe and explain the behavior and the experience of the individual is the task of psychologists. Analysis of environmental arrangements and student activities that describe and explain the association of conceptual structures of the physical and biological worlds with the discriminative behavior of students is the task of the educators. Here our primary emphasis will be on the nature of the individual as it has a bearing on the learning of the structure of the conceptual systems of science and the development of scientific inquiry skills.

First, let us define learning. We can discriminate at least two uses of the term "learning": (a) one by classroom teachers and (b) another by experimental psychologists. The schoolteacher uses the term "learning" to refer to changes in performance in the classroom; the experimental psychologist uses the term to refer to response changes under highly controlled laboratory conditions. In the classroom, learning refers to complex behavior; in the laboratory it is limited to simple behavior. The difference between the two uses of the term is so great that there has been until recently little influence of the laboratory on classroom conceptions, and vice versa. To understand the use of the term "learning" by experimental psychologists we must understand the constructs and relations within a conceptual structure of psychology. If we understand the described conceptual structure of psychology, we shall also be able to understand in a precise way the use of the term "learning" by the classroom teacher.

LEARNING DEFINED

WITHIN THE CONCEPTUAL STRUCTURE OF PSYCHOLOGY

We shall briefly characterize the "conceptual structure" of psychology for several reasons. First, it provides an elementary example of a conceptual organization of a field. Second, this structure of psychology can be used as an inventory of problems for the field of education. (For instance, the design of schools and classrooms is related to the findings of physiological psychology; the constitution and sequences of curricula are related to the problems of learning; the assignment of pupils to classes is related to the study of individual differences, and so forth.) Third, this organization of the field of psychology embodies the research organization of a psychological conception of man. Fourth, within the discriminations and relations of the field of psychology so conceived, the differences in the meanings of the term "learning" as used by the teachers and by the experimental psychologists can be clarified.

Both behavioristic and psychoanalytical psychology are important divisions of psychology, but the behavioristic is of greater importance for the study of learning. We shall call behavioristic psychology—that psychology which developed from the philosophy of British empiricism and American pragmatism—"psychology$_B$." Psychology$_B$ is characteristically experimental, quantitative, and limited in theoretical superstructure. Psychoanalytic psychology, which we shall call "psychology$_P$," came from the philosophy of German idealism and is characteristically clinical, non-quantitative, and has an elaborate theoretical superstructure. Within the tradition of the biological sciences, psychology$_B$, so-called "scientific psychology," is primarily a study of function, that is, behavior. The notion of structure appears as relations between behaviors. It is concerned with the study of the *behavior* of organisms. Within the tradition of the humanities and philosophy, which Freud combined with a medical empiricism, psychology$_P$ is primarily a study of consciousness, its determinants, and its systems of intellectual and artistic products. Psychoanalysis is mainly concerned with the study of the *experience* of persons.

Structure of Behavioral Psychology

The discipline of psychology$_B$ has three divisions that are similar to those found in other sciences: (a) basic scientific fields, (b) developmental fields, and (c) applied fields. This psychology does not have a united theoretical superstructure, and thus it has no theories similar to those of the contemporary physical sciences. The present state of psychology$_B$, historically comparable to that of physics at the time of Galileo, can be given by listing the several sets of variables that are used in describing and predicting behavior. In all of the following relationships, the dependent variable is *behavior* and the independent variables are those which the observer controls or observes in a natural context and/or controls by statistical analysis after the observations have been made:

I. Basic Scientific Fields

Behavior = f (physiological variables—sensation, perception, effects of drugs, damage to central nervous system, etc.)

Behavior = f (learning variables—nature, amount, and delay of reinforcement, generalization and discrimination, inhibition, etc.)

Behavior = f (capacity variables—IQ, interests, values, aptitudes, abilities, achievement tests, etc.)

Behavior = f (personality variables—anxiety, conflict, frustration, dependence, hostility, ego-strength, etc.)

Behavior = f (social group variables—size of group, communication within group, personality constitution of group, etc.)

In the sense that physics was traditionally organized into several fields such as mechanics, optics, heat, electricity, and nuclear physics, so psychology_B is organized into the fields of sensory and central processes affecting behavior, learning processes, the measurement of capacities, personality processes, and social group processes. *Behavior* is what is observed and measured and is related to environmental or past history variables.

The developmental fields are similar to the study of hereditary mechanics in physics. It is not enough to know, for instance, the laws of interaction of a system (say a particular fiber) with its environment. The history of its deformations and strains must also be known, because these set limits on the operational boundaries of the physical system of the fiber. The human organism is one of the most complex physical systems when viewed from its capacity to embody structurally and reflect functionally the deformations of past transactions with its environment. The developmental fields of psychology_B are:

II. Developmental Fields

Behavior = f (childhood variables, ages 0-12 years)

Behavior = f (adolescent variables, ages 10-20 years)

Behavior = f (mature age variables, ages 18-50 years)

Behavior = f (late age variables, ages over 50 years)

It is characteristic of the growth processes of *homo sapiens* that certain social and self concepts are appropriate to particular ages, that the organism at different ages has different experiences, capacities, skills, interests, and values. The fields of child psychology and adolescent psychology are concerned with those conditions that affect behaviors which are peculiar to particular ages. The developmental fields are not basic in the scientific scheme of things, in that there are no new laws of learning that apply only to children or that differentiate children from adolescents. The same general laws apply. For instance, if behavior is reinforced in a particular situation, there will be an increase in the probability of that behavior's occurring in future similar situations. These fields specify the existing sets of acquired skills, the dimensions of meanings, and the nature of what will constitute a reinforcement for a child as distinguished from a reinforcement for an adult. Children may be reinforced in an experiment with gold stars or jelly beans, an adolescent may be reinforced by the approval of his peers, but an adult may need money or approval of other adults for reinforcement.

The third division is composed of problems engendered by the fitting of basic scientific laws and characteristics of a person at a particular age into the variables of a specific setting.

III. Applied Fields

Behavior = f(school setting variables—educational psychology)
Behavior = f(clinic or hospital setting variables—clinical psychology)
Behavior = f(industrial setting variables—industrial psychology)
Behavior = f(military organization setting variables—military psychology)

To return to our differentiation of the term "learning" as it is used by the classroom teacher and the experimental psychologist, the following distinctions can be made: Let us call what the classroom teacher sees as classroom learning, "learning$_C$." Learning$_C$ is determined by sensory, learning, and social group processes; differences in intelligence, personality, and age; and the pecularities of the subject matter and school situations. The experimental psychologist constructs experiments to isolate the learning processes from the effects of these many variables. Let us refer to laboratory learning as "learning$_L$."

The term "learning" in the classroom refers to complex behavior, but in the laboratory it is limited to simple behavior. Until the advent of programed learning textbooks and teaching machines, learning$_C$ was defined in gross terms and measured by general tests, while learning$_L$ was confined to simple situations and behaviors. Programed learning by knowing "instructional simples" and the techniques of linking them into complex instructional chains relates laboratory learning to classroom learning.

LEARNING AS THE ACQUISITION OF DISCRIMINATIVE RESPONSES

The procedures of control and shaping of the behavior of a student for the learning of science can be—and are—affected by architecture, by reinforcements, and by the kinds of stimuli experienced by the subject.

The function of the teacher is to provide the student with discriminative stimuli, discriminative responses, reinforcements, and the motivation necessary for the shaping and chaining of student behaviors. Teachers selectively reinforce, shape, and chain behavior through assignments, approval in the classroom tests, and grades. The shop and gym teachers and athletic coaches are in a powerful position to control student behavior. These teachers frequently possess skills desired by the student and can dispense powerful reinforcements, such as positions on an athletic team or the use of facilities.

The role of reinforcements and their variety and control are of especial importance in the learning situation. Good students have their lives arranged so that they have a consistent set of reinforcement schedules that are in accord with those of the school.

CONTROL OF BEHAVIOR

Our goals are to understand: (1) the general control of behavior and (2) the control of verbal behavior involved in the structure and linguistics of scientific activity. The control procedures for shaping general behavior are the framework for the shaping of verbal behavior. In this section we shall discuss the general principles of controlling behavior. The teacher must exercise this control as a preliminary adjunct to teaching science.

Architecture

The shaping of student behavior in the classroom has usually been accomplished to a large extent by the physical arrangements of the school. A difference between a school and a factory, despite some surprising external architectural similarities, is that the traditional design of the school controls the behavior of students and directs it toward the teacher, whereas the design of a factory controls the behavior of the workers by directing it toward the production line. The physical arrangements of most classrooms are intended to facilitate communication between student and teacher, while limiting it between students. In science laboratories, as well as in many newer classrooms, the physical arrangement of work conditions results in an informal atmosphere and easy discussion between students on mutual problems. Libraries, if they are well designed, minimize discussion between students and let each student study by himself without disturbing his neighbor. Some students, particularly those from families that are economically disadvantaged, have difficulty studying at home because of the physical and social arrangements of the home. Therefore, in economically deprived areas, the school should plan space and time to help these students learn study skills.

Reinforcement

Reinforcement has been defined as any event which increases the probability of occurrence on a future similar occasion of the preceding response. This is a minimal definition that gives no clue as to the nature of the reinforcing event. It may be food to a hungry animal, a jelly bean to a child, social approval to an adolescent, money to an adult, finding that a response is correct to a student working on a programed instructional frame, or the perception (discovery) of the "meaning" of an activity.

Reinforcements increase the probability of recurrence in a similar future situation of responses which they follow. The physical dimensions of a reinforcement can thus be specified:

1. *Timing of reinforcement.* Reinforcement which follows a response immediately is more effective than one that is delayed minutes, hours, or days. Immediate reinforcement is one of the two major rationales of programed teaching. The other is that complex behaviors are built out of assemblages of simple behaviors.
2. *Amplitude of reinforcement.* Generally speaking, the amount of reinforcement has a relationship to the need state under which the organism is operating. Large reinforcements that are relevant to the need are more reinforcing than are small reinforcements. However, if the reinforcement is so large that the motivation for responding is appreciably decreased, the organism will stop responding. If a continuous series of responses is desired, the reinforcements should be given in amounts that do not markedly reduce the motivational state. One consequence of this line of thought is that if a student is not motivated, there will be no possibility of reinforcement. A second consequence is that motivation without appropriate reinforcement of the desirable behavior does not result in learning.
3. *Number of reinforcements.* If the task is a complex one, or

one in which there is an assemblage of small discriminations, then the number of reinforcements will be related to the general performance. That is, the more reinforcements, the better the performance.

4. *Schedules of reinforcements.* A decision can be made by the teacher about how reinforcements shall be given. This will be discussed later, but one illustration that demonstrates the effect of reinforcement schedules on behavior is the question of whether to reinforce the *time* spent on a job or the *completion* of a job. In some manufacturing situations, the employee gets reinforced for the hours on a job, regardless of the number of units of work he produces; in other cases his pay is related to the number of completed pieces of work. In the latter situation, output is clearly superior. A similar point can be made that some schoolteachers simply reinforce students with approval for time spent quietly in class, while for others the reinforcements are based upon the productive work done in and outside of the class.

Stimuli

The construct "discrimination" applies to both stimuli and responses. For example, we can speak of discriminative stimuli (sets of which are scientific constructs and laws) and discriminative responses (sets of which constitute activities of the scientist either in research or in reporting his research). To take a simple example (from Holland and Skinner [3]), a girl whose facial expression has an "approachable" look is more likely to be asked for a date than if she has an "aloof" look. She may assume an "approachable" expression to exert stimulus control over a young man's behavior. To transfer this example to the teaching situation, consider the relation of the teacher to the student. The "approachable" teacher is more likely to be asked more questions than is the "aloof" teacher. The "approachable" look is a stimulus that is more likely to be followed by a reinforcement than is the "aloof" look. A student easily learns to discriminate between "approachable" and "unapproachable" teachers, between teachers who have a "good sense of humor" and "old grouches." The manner of these teachers has become a discriminative stimulus which controls the behavior of students. When a student responds selectively to the teacher, depending upon whether he is in a "good" or "grouchy" mood, then the student is making a discriminative response.

By definition, a **discriminative stimulus** is the occasion upon which a response is followed by a reinforcement. A discriminative stimulus is established by a schedule of reinforcement such that when the stimulus that is to be discriminated is present and a response is emitted, then the reinforcement is given. In the absence of the particular stimulus, if a response is given it is not reinforced. Responses which are emitted and reinforced gain in strength; those emitted and not reinforced weaken in strength. Students learn to watch the moods of the teacher and respond when the teacher is "approachable" in anticipation of being reinforced, i.e., given approval, encouragement, information, direction, etc., and learn not to respond when the teacher is "grouchy." Very fine discriminations can be made by students. For example, an injunction by the teacher to behave well in the classroom is ignored until a slight rise in pitch of the teacher's voice indicates that disciplinary action will be immediately forthcoming unless student behavior changes.

Take the simple case of an animal being trained in a standard laboratory experiment. A decision is made to reinforce a response—say pressing a bar when a light is on. The light will be called the discriminative stimulus. The response of pressing the bar will not be reinforced when the light is off. The two stimulus conditions (light on and light off) soon become discriminated by the animal, and the presence of the light becomes the occasion to press the bar. The light gains the property of controlling the emission of the response. From basic research of this type, the whole theory of the teaching machine and programed learning was developed. The question in the frame is the occasion for the emission of a discriminative response. In the careful building up of the response tendencies, sharp discriminations are made between various concepts to be learned and the different responses to these concepts. All of this is done by the repeated presentation of the discriminative stimulus and differentiating it from those stimuli that are not correct, that is, not reinforced.

For a student working through a programed instructional sequence, behavior is under strong stimulus control by the questions in the frame. Education has as a goal a strong commitment to the development of self-directed intellectual activity. Teaching program sequences can, in fact, be programed so that the stimulus control comes from ideas within the internal structure of conceptual systems held by the individual, rather than being elicited by the external stimulus of the program or the external stimulus of a presumed authority. The instructional sequence for programed instruction, as well as the psychoanalyst or the teacher, should be judged by the success of the student in solving problems independently.

Schedules of Reinforcement

As already pointed out, a teacher can reinforce, shape, and chain behavior, as well as place it under stimulus control. Each student is in a complex world of reinforcement schedules. His behavior is shaped and controlled by reinforcement schedules in the home, community, and peer group, as well as in the classroom. The teacher will experience difficulty when his reinforcement schedules for the student must compete with other schedules that exercise a more powerful control over student behavior.

Good students have their lives arranged so that they have a consistent set of reinforcement schedules that are congruent with those provided by the school. Fortunate are both the students and the teachers who live in a scientific community, such as those around missile bases, in which the school, the family, and the community all reinforce the learning of science. The advantage for a student living in a boarding school, such as an English public school, is that the whole pattern of life activities is run on schedules of reinforcement that are consistent with those of the educational activities.

THE LANGUAGE OF SCIENCE AS DISCRIMINATIVE STIMULI

Scientific language exhibits the general *characteristics* of precision, generality, confirmability, and coherence. For students to be successful and comfortable with this language will require, for many, a change in their style of relating to the world.

Characteristics of Scientific Language

The intention of scientists is to describe, predict, explain, and control phenomena.[1] The analysis of terms like "description," "prediction," and "explanation" are problems of the philosopher of science, not problems of the psychologist. These terms are important for the psychologist and the teacher as concepts which

[1] There is some question as to whether the control of phenomena is entailed in pure science. Since some scientists commit themselves to a pragmatic conception of truth in which stress is placed upon procedures of control, the notion of control has been included in the goals of science. The majority point of view is that, although description and explanation are sometimes difficult to differentiate, explanation at least is the intent of scientists. The distinction usually made is that description is "giving an accounting of" while explanation is "providing an accounting for" physical phenomena.

have to be communicated to students *about* scientific activity. Part of the resistance of students to the learning of scientific systems may be due to the fact that preliminary justification for the systems (describing, explaining, and predicting physical phenomena) has not been accepted as worthwhile. If these scientific characteristics are not valued, then scientific activity is, in fact, busywork or fancy bookkeeping.

The **precision** of scientific statements has two properties:

1. The terms and relationships have a close correspondence to the phenomena to which they refer; that is, the definitions that coordinate the statements of science to factual states of affairs are operationally specific.
2. The statements may be descriptions of particulars, semi-quantitative statements, or statements that are fully quantitative.

It is important to note that precision is not necessarily associated with quantitative or mathematical statements. Nor is it associated intrinsically with experimentation. Statements in biology, for instance, may be precise without having quantitative features. Teaching of precision in elementary school science has traditionally proceeded from descriptions of particular events, to semi-metrical statements, to fully metrical statements.

Precision of mathematical and scientific statements frequently requires a change in the verbal habits of students and even in those of the teacher. Increased precision of statement is frequently not understood as a requirement for precise relationships. Many of the transactions of our ordinary life can be conducted successfully with imprecise language, rudimentary mathematics, and vague relations to spatial and temporal contexts.

The concept of **generality** implies that statements of a scientific type have "exceptionless validity" at whatever time and place if the conditions of the application of the statement are fulfilled. The idea of the independence of a specific observer, at a particular time and place, requires a capacity for abstraction on the part of a student. The concept that physical phenomena are independent of the observer runs counter to most of his experiences of physical phenomena, which have been local, specific, and related to his need states.

Confirmability is another of the important characteristics of scientific statements. This criterion requires that, for a statement to have meaning, some way of directly or indirectly testing it must exist. A precondition for this requirement is that statements must be precise and general to permit confirmation. If a statement is not precise, what it applies to is not clear. If it is general, it may be confirmed by another person in another time and place. Confirmation is, naturally, only a matter of degree and never final. It must not be confused with proof, which is a property of logical systems like mathematics. In elementary science, stress on experimentation and confirmation of scientific statements is well advised. The student, however, is made aware that the history of science is replete with examples of theories whose merit rests as much on conceptual coherence as on confirmation of predictions.

To stress the conceptual systems of science is to emphasize the coherence of scientific statements. Fundamentally, statements of science should not contradict each other.

Scientific, Unscientific, and Nonscientific

We shall differentiate between the terms "scientific," "unscientific," and "nonscientific" to distinguish the general characteristics of the language of science. The convention is to call statements "scientific" if they are emitted under conditions which are controlled by certain intentions and have certain characteristics. The term "unscientific" refers to statements that have the intentions of science, but not its characteristics. "Nonscientific" statements have neither the intention nor the characteristics of scientific statements.

Concepts and Constructs

Concepts of science have many of the same relations as the terms of any language. There are at least four relations: (1) to things, (2) to each other in laws, (3) to each other in hierarchies of laws within inductive and deductive systems, and (4) to the people who use them.

A typical confusion among science educators is that the concept in an explanatory scientific system is not distinguished from the concept in the thought of an explanatory system of a young student of science. To minimize this double reference of the term "concept," concepts in science will be referred to hereafter as "constructs" and concepts in the thought of the student will be called "concepts."

DISCRIMINATIVE RESPONSES

In Statements and Procedures of Scientific Inquiry

Personality traits that facilitate success in learning science are closely related to the nature of the task in learning scientific conceptual systems. The teacher's understanding of reinforcement and skill in using certain types of reinforcement can greatly aid the student in reconciling personality and the demands of scientific study.

The learning of the science constructs is based upon the recognition that while one first comes to simple observations, the conceptual structures themselves are built upon abstractions related to special conditions of scientific deduction and controlled observation.

Scientific statements, from the point of view of a psychologist, may be considered either (1) stimuli, when they direct or elicit behavior from a scientist or (2) responses, when a scientist emits them.

A scientist responds to different stimuli, says and does different things than does the nonscientist. With his conceptual systems, he interprets the experience he has with the world and regulates his commerce with it differently than does the nonscientist. To a medium level of competence, the acquisition of scientific conceptual systems is not a difficult educational problem. Primitive or nonindustrialized countries, for instance, like China and the Soviet Union of fifty years ago, can in a short time build up a cadre of scientific workers. By distinction, it takes much more time to build up those discriminations that result in a great literature. Conceptual systems about the physical world are easier to construct than are those about the human world, due largely to the precision with which the physical theories can be formulated and checked.

The type of personality that supports the learning of scientific material meshes with the nature of the task in learning scientific conceptual systems. The massive conceptual structure of scientific theory and facts requires careful, persistent, steady, and orderly study. These particular kinds of study may be reinforced in the classroom if a decision is made to do so, for these are personal styles of learning that support or are congruent with the learning of scientific material. In Switzerland, school children, in addition to being graded on what they know, are graded on industry (*der Fleiss*). In Austria they also receive a grade on the care with which they do their work (*die Sorge*). Singling out these behaviors and grading the industry and care with which work is done help students discriminate selectively which responses will be reinforced. Congruent with these two dimensions, the learning of science in these school systems is of a high order, despite facilities that may be far from adequate.

The major difference between scientific and nonscientific activities, as we have indicated earlier, is due to the controls put on the meaning of scientific statements, that they are meaningful only if they are directly or indirectly confirmable. There is, presumably, a "scientific method" which provides procedures for the exact determination of the degrees of confirmation of any particular statement. However, it is better to speak of "scientific methods" and to realize that what is involved in scientific activity is generalized problem-solving by a variety of methods.

While ultimately the appeal of scientific method is to confirmation in direct experience of the scientist, this doctrine has been used to extremes without much thought about logical consistency in the programs of science training. The statement "All zebras are members of the family of horses, and these members have stripes" is a classic example of the statement of a scientific definition. It is not confirmable by direct experience. This statement by a young science student may appears as "Zebras are horses with stripes." The statement depends not upon an acquaintance with zebras, but with the notion of horses and the notion of stripes. It is true that the student bases this description of zebras upon the basic discrimination of horses and stripes, so there is an ultimate reference to direct experience. It is to be stressed, however, that much of scientific conceptual material is composed of constructs that are defined by combining descriptive properties rather than simply pointing to an instance of the concept. The learning of the conceptual structures of science is based upon the recognition that while at the foundation of the scientific structure there are simple observations in terms of grams, centimeters, and seconds, for example, the conceptual structures themselves are built upon abstractions and descriptions that bring order into our everyday experience, but whose relation to that experience depends upon very special conditions of scientific deduction and controlled observation.

Classified by Conceptual Systems of Science

The capacity to grasp and understand a conceptual system is of vital importance in learning in the field of science—or of mathematics. The difficulty in grasping a conceptual scheme may result in failure ever to learn the coordination of the conceptual forms to experience or reality. Understanding the conceptual scheme is a key to transfer of learning.

While the ultimate acceptance of scientific statements is an appeal to confirmation in experience, it should be clear that a psychological approach to the learning of science does not imply that all scientific statements must be directly verified by the student. In stressing a "psychological" approach to the learning of fields of science, particularly in its elementary phases, it is easy to misperceive significant aspects both of conceptual systems and of discriminative responses.

The classic case of a conceptual system or a set of conceptual systems, is mathematics. Learning of mathematics involves in almost pure form the issues raised between psychology and conceptual systems.

Addition, subtraction, multiplication, and division with integers, usually under 10, provides the experience base of the conceptual system. Thus, these basic operations are confirmed in experience. However, the child who multiplies 206 x 36 does not go through the same discriminative responses that are used in the learning of 2 x 3.

Two or three different procedures may be used to check 206 x 36, but it is unlikely that a child will construct a square 206 units by 36 units and then count the resulting number of units. The calculation is performed by rules of procedures based upon definitions of the system of natural numbers and postulates of algebra. The relevant discriminative responses are thus specified by the conceptual system.

The procedural rules, such as the postulates of algebra, specify the responses allowable in the changes in arrangements of data. Thus $a+b=b+a$ is an allowable operation, or response. The learning of precise definitions and relationships and the allowable transformation of these relationships is fundamental in the learning of science. Direct experience confirmation *and* conformity to transformation rules of the conceptual system are both discriminative responses that are to be learned.

The application of mathematics has the major problem (presented in slightly less degree in science) of its relation to experience. The difficulty is due to the abstraction of the mathematical constructs and the reliance on formal rules of manipulation. Intuitive perception of causal relations can occur with use of scientific constructs. Two questions arise:

1. How do the mathematical or scientific forms apply to the world?
2. How is the world to be conceptualized in terms of mathematical or scientific forms?

For many persons the manipulations of algebra are easy, but the word problems are impossible. The questions are how to apply mathematical or scientific forms and how to give structure to a problem.

The psychologist would hold that the relations between the conceptual system and experience (reality) are learned like any other relationships. A neurotic reaction to difficulty in translating algebra into word problems, or vice versa, is to avoid this task. This avoidance behavior, which is reinforced by reduction of anxiety and reduction of a sense of helplessness, results in a failure ever to learn the coordination of the conceptual forms with the forms of experience or reality. The coordinations are learned, as Dewey held, by doing them. The technique of coordination is one of programing easy problems, giving immediate reinforcement for correct coordination, and then increasing the *difficulty* and the *variety* of the problems. The understanding of a construct, a generalization, a law, a principle, a conceptual system means that the range of application to instances is known. A measure of the capacity to transfer learning is knowledge of the range of application of a principle.

THE LEARNING OF INHIBITION

The negative process of inhibition can also be learned and often is learned through the student's lack of success or through the improper control of response or reinforcement by teachers and parents.

Instructional programs and methods that avoid negative stimuli and favor innovations such as the student's control of his own path through the subject matter may lessen the possibility of creating or reinforcing low self-esteem *vis à vis* science.

The position can be taken that the science teachers of America are, without exception, excellent teachers, and that their students, also without exception, learn a great deal. A careful analysis of the learning situation, however, indicates that the teachers may not be great teachers of science, and the students may not be learning much science. What, in fact, frequently happens is that when students are confronted with scientific subject matter, they learn to be anxious, bored, fatigued, or frustrated, or to regard themselves with low self-esteem.

Anxiety

To teach an anxiety response to scientific material is very easy. The teacher simply arranges conditions in which he is punitive in response to student failures, makes demands on the students that are unrealistic in terms of their abilities or preparation, and arouses fear in the students. A student may reinforce his anxiety by psychologically withdrawing from such a situation. This reduces his anxiety. He then avoids reading or thinking about the content of science. Some students will refuse to participate in class and will even play inordinately stupid roles so the teacher will not call on them.

Boredom

To learn bored responses to scientific tasks is also very easy. Boredom is only rarely an indication of scientific acumen or superiority. More often it is a way of coping with anxiety and avoiding situations in which anxiety might be provoked. Boredom is not only a problem for students; it is sometimes thought to be an occupational hazard of teachers. Although the "bored" teacher may claim that his task is not intellectually challenging, the scientific complexity of transmitting the conceptual structures of science into the discriminative responses of students is clearly a very intellectually challenging problem.

Fatigue

We can discriminate between two types of fatigue: One comes from work done, like studying science for four hours straight and simply being tired but able to continue the study after a rest. Another is a condition of fatigue, lassitude, and boredom that is a response to even the thought of studying science and that may continue throughout life. The first type of inhibition is called *reactive inhibition;* the second type is called conditioned or *learned inhibition.* Learned inhibition quickly attaches itself to topics like mathematics, sciences, languages, music, or any complex subject matter. The work of assimilating these subjects stops short of reaching competency and goals, and is thus not reinforced.

In a condition of fatigue, the reinforced response is the shift of behavior from arduous study to more pleasant tasks. This response results in a reduction of the fatigue and thus reinforces the shift. As a result, when the student starts to study science, he may remember that he has to make an important telephone call or perform some neglected task, or he may suddenly feel sleepy.

Frustration

Frustration occurs when goal-oriented behaviors are stopped short of the goal. There are many reactions to frustration, depending upon what has been reinforced in the past history of a student. One reaction is to aggress against the frustrating object or person; another is to take the blame on oneself; a third is to deny that there is any frustration. One might also defend one's ego, concentrate on contemplating the obstacle that caused the frustration, or continue trying to solve the problem. Consider a scientific experiment in which the required results are not obtained. The student can (1) blame the teacher, the apparatus, or the instructions, (2) blame himself, or (3) deny that the outcome of the experiment was important. He can further say that (4) it was not his fault, or (5) that the defective instructions, apparatus, or teacher is an educational misfortune, or (6) he could try to solve the problem in some other way.

It is characteristic of families and of classroom teachers that they may unconsciously (or consciously) reinforce one of these types of responses. For example, they may reinforce these responses by retreat in the face of aggression or by expressing sympathy. Such reinforcement increases the probability that the defensive response of the student will recur on the next similar occasion.

Low Self-Esteem

Low self-esteem is one of the by-products of our school system. This is in part due to the social organization of our curricula in which major rewards are given to a small percentage of students (those getting A's), while strong negative stimuli are given to those getting D's and F's. The academic self-esteem of students is controlled by methods of teaching and assignment of grades. One of the advantages of programed instruction is that grading is based upon self-directed achievement at a pace controlled by the students.

DEVELOPMENTAL STAGES

To know the laws of learning or the particular structure of intellect is not enough for the teaching of science to students. A teacher must also have some understanding of the stage of development of the students. Two dimensions are important:

1. Since teaching is a social process, it is important to know the stage of social development of students.
2. Since teaching involves the development or modification of students' schemes about the physical world, it is also important to have some idea about the schemes that are characteristic of the developing student.

Erikson, one of the most original psychoanalysts since Freud, has constructed a theory of a person's social development. [5] Piaget, a Swiss naturalist with philosophical learnings, has given us the best studies on the growth of a child's understanding of the physical world. [6]

Individual Development

Erikson and Piaget share a set of assumptions about the nature of the development of an indvidual that is common in the work of many investigators in child psychology:

1. Each child has a history of continuous development.
2. This development depends jointly on the evolution of the physical system of the child and upon his transactions with his environment.
3. The character of later stages depends upon early stages.
4. Quantitative changes in tendencies to respond result in qualitative changes in behavior that are sufficiently different that "stages" can be discriminated.

It is characteristic of human beings that they are the carriers of their history of experiences. They are also self-reflective; that is, a person develops in his relations with the world not only schemes about the nature of physical order and systems of religious and social belief, but also schemes about himself. These schemes are composed of orienting attitudes toward the world and himself, sets of rules that regulate his behavior, and assumptions and hypotheses about the inner relations of his personality.

Erikson's scheme of social development (up to the adolescent stage) is as follows:

Infancy	Trust vs Mistrust				
Early Childhood		Autonomy vs Shame, Doubt			
Play Age			Initiative vs Guilt		
School Age				Industry vs Inferiority	
Adolescence					Identity vs Diffusion (Confusion)

The significance of the scheme is that it provides:

1. A description of the successive critical periods of social development and their outcomes

2. An understanding of what to expect in terms of the history of students who have and have not learned to work
3. The basis of remedial action to help socially malajusted students learn the conceptual systems of science
4. An indication of what will be a reinforcing event in a social situation at particular stages of development.

Infancy is a stage of dependence and helplessness. In this stage the infant learns either to expect support and approval and to depend on others, or he learns that placing trust in others results in vulnerability to attack. If trust is given and received, then the infant learns to trust himself and to take the first steps toward autonomous behavior. The basis of autonomy is in trust, in the same way that initiative requires previous experience of autonomy as a precondition. Success in the development of initiative is the substructure of industry, the ability to work and study. Erikson's scheme has the implication that if a student does not learn to work, the demands of school will result in failures of responsibility and in low self-esteem. The sense of inferiority that develops in the maladjusted student will probably also have concomitant feelings of generalized guilt, shame, doubt, and mistrust.

At each stage of development, the social relations of an individual permit a distinctive social pattern that can be differentiated from earlier stages. Social life is so patterned that at each specific stage the time and the conditions for specific social learnings are optimal. However, there is some evidence that children who have not learned trust (for example) in infancy are not necessarily permanently damaged. They may learn to discriminate who can be trusted in relations with significant adults, such as neighbors, teachers, or community group leaders. If a child learns to mistrust his social world, this does not mean that he will not learn autonomy, but it does mean that learning autonomy will be more difficult. The autonomy he learns, however, will reduce the anxiety generated by mistrustful relations with the social world.

The symptom picture of the young adolescent will be some mixture of the traits given in Erikson's scheme. The scheme is presented to alert the teacher of science to the features of social behavior that will affect the relations of the student with the teacher. With the student who has had optimal development, there will usually be no problem if the course syllabus is within his intellectual capacity. A psychologist would stress, however, that many problems of learning in school are inextricably mixed with the social relations of the student and teacher.

Erikson's scheme gives the teacher some cues as to what will constitute a reinforcement to an adolescent. If a student has had a history of unfortunate resolution of the conflicts of these social periods, he will defend himself against shame, doubt, guilt, and inferiority feelings, and will not have a relation of trust with his teachers. A teacher should not confirm a weak student's hypotheses that adults are not to be trusted or that he, the student, is basically inferior. The teacher is cautioned particularly not to shame a student who may be having trouble learning science, not to make comparisons between strong and weak students, and not to exhibit doubt that a student has the capacity to learn science. Above all, a sense of fairness on the part of the teacher is to be stressed. A teacher must communicate in small ways a sense of trust to a student in carefully chosen situations where the trust relationship does not strain the capabilities of a student to live up to it.

Intellectual Evolution

Piaget has constructed a scheme that depicts the intellectual evolution of a child. Within this general intellectual development, he has also schematized the growth of a child's conception of causality. This theory has not been confirmed in detail by American investigators, but at least the types of thinking and the beginning and end of the sequence are easily identified. As a biologist, Piaget is most interested in the changing relations of an individual to the world. For him, a child's adaptation is distinguished by two ways of coping with the world:

1. By *adaptive* changes to the outer world
2. By *incorporation or assimilation* of the outer to the inner world where the structure of the organism permits it.

The notions of adaptation and assimilation are held to apply to the relation of a student to intellectual ideas.

According to Piaget, there are three planes of intellectual development:

1. Sensory-motor activity
2. Egocentric thought
3. Rational thought

In the sensory-motor stage, an infant adapts to the external world by "creating" it from his experiences of external realities. He learns that there is a world quite apart from his actions.

In early childhood he has passed to the level of egocentric thought. Although knowing the permanence of concrete objects, he has not yet fully developed concepts such as matter, weight, movement, number, or logic. He has passed from the initial egocentricity of the sensory stage to logical and social egocentricity. He is unable to take the perspective of another person. A young child's personal perspective is absolute, not relative.

As a child grows older, he gradually learns the relativity which is necessary for objective conceptions to emerge. The essence of rational coordination is then to be found in the logic of relations; that is, in the fundamental group of operations which assures the reciprocity of individual perspectives and the relativity of the facts of experience. The logic of relations gradually makes a child understand (usually between the ages of seven and eleven) that the left and right hands are not absolute, but that his own left corresponds to the right of the individual opposite him.

Causal Thinking

Piaget originally delineated 17 types of causal thinking; for our purposes, Watson's organization of these into five categories will suffice: [8]

1. *Phenomenistic*—Two facts, although unrelated except by contiguity in time and space, are linked causally: Pebble sinks to the bottom of the water because it is white.
2. *Animistic Causality*—An internal biological tendency that is both alive and conscious is assigned causative properties: Clouds move because they are alive.
3. *Dynamic Causality*—Animism is gone, but the child still sees in objects forces that are capable of explaining activity and movement: The ball falls because it has an affinity for the ground.
4. *Mechanical Causality*—Causality is explained by contact and transference of movement, not by internal force: The wind pushes the clouds or pedals make a bicycle go.
5. *Explanation by Logical Deduction*—Causality is explained by the principle of sufficient reason: Water flows into the second of the connected tubes because water can go equally in both directions.

The first three types are precausal and egocentric, while mechanical causality may be considered as transitional. Explanation by logical definition belongs to the category of relation coordination.

COMMON SENSE ADVICE TO TEACHERS

Teachers with large classes cannot expect to assess individual needs and vary teaching techniques accordingly, but they can adopt certain useful techniques based on the understanding and use of discriminative stimuli and direction of student responses. Teachers, as well as students, are constantly reinforced in behavior and should seek to establish a classroom atmosphere that is mutually reinforcing. Certain common sense advice, not very different from that usually given to prospective teachers, can aid the teacher in this task.

If a teacher knows the instructional material well, he can then provide the discriminative stimuli to elicit the discriminative responses. He will also know the sequences of the shaping and chaining of student responses. If a teacher knows the individual students, and the students admire the teacher, approval of the teacher is a powerful reinforcement in the learning situation. Not only is the approval of the teacher reinforcing, but his suggestions are also powerfully motivating. A teacher who knows his subject and his students is thus in a position to check the growth of the anxiety, boredom, frustration, and low self-esteem often associated with study.

A teacher should *like* the individual student for both the student's sake and his own. If a student progresses, and the student is liked by the teacher, the teacher's behavior is reinforced. To maintain morale in the classroom, the instructional situation must be mutually reinforcing for the students and for the teacher.

It is conceivable that a teacher may know the structure of science well, know and like the students, and yet not care whether they learn any science. The teacher who claims he is not really a teacher of *science*, but something else, demeans himself by this claim and may not communicate an enthusiasm for science to his students. If a teacher really cares for students and is committed to their education, then teaching is a way of self-fulfillment and self-realization.

THE STUDENTS' PARTICIPATION

The subject of learning in the classroom cannot be closed without some consideration of motivation, memory and retention, and transfer of training.

Although the drive reduction concept of reinforcement implies **motivation**, it has not been explicitly discussed here. With good students, almost by definition, there is no problem of motivation.

If a student has a history of low motivation in school, a teacher may within reasonable limits try to break patterns of educational defeat. He may do this by helping the student discriminate his past history of educational frustration from the opportunity to learn in the present science class. Both underachieving and overachieving students tend to be anxious. Underachievement or overachievement can be determined by an estimate of what a student is capable of, as determined by his measured IQ and other tests. Underachieving students tend to reduce their anxiety by withdrawal from educational frustrations. This withdrawal is often manifested by fantasies in the classroom, self-preoccupation, and concentrated interest in athletics, outside work, or the opposite sex. By contrast, the overachiever copes with his academic anxieties by increasing the amount of work spent on his studies.

The problems of **memory and retention** in studying conceptual schemes should theoretically be less than are usually found in the study of science. The relational structure of conceptual schemes facilitates memory and retention of scientific statements. Conceptual schemes give relational meaning and "contain" separate facts.

The problem of **transfer of training**, the application of classroom learning to problems outside of the classroom, depends upon whether the student "learns to transfer." Some of the so-called psychologically oriented approaches to the teaching of science, and the teaching of science teachers, have been so exclusively concerned with the problems of the applications of science that the basic structure of the science is not well learned. Learning basic conceptual structures provides a psychologically economical set of relations for the use of science. The science that is not learned well is applied with difficulty to general situations.

Teaching of applications also involves an appreciation of the fact that relatively few instances of "pure" textbook cases exist in complex reality. The student must learn to recognize that adjustments will have to be made in handling equipment not of special laboratory design in situations that do not replicate laboratory control. In spite of these additional difficulties for the observation and control of physical phenomena outside of the laboratory, transfer refers to specific behaviors that are to be learned by special exercises in the classroom learning situation.

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Introductory Textbooks

The general introductory textbooks in psychology have been written by men of intellectual and research stature in the field and are thus of unusually good quality. The field of psychology changes so rapidly that textbooks are revised approximately every five years. An older textbook is of questionable value in understanding current theories and findings in the field. The only exception is the Skinner book below, written in 1952. The Holland and Skinner is a paperback programed instruction text.

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3. Holland, J. E., and Skinner, B. F. *The Analysis of Behavior.* McGraw-Hill Book Company, New York. 1961.
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Intermediate Textbooks

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CREATIVITY

and productive thinking in science education

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THE SCIENTIFIC venture is, fundamentally, a human venture. There is nothing more basic in science than the scientist himself, for it is in the mind of man that observations are fitted into patterns, new ideas are created, and strategies are devised for further searching. All too often, however, the importance of the human being in the scientific effort seems to have been overlooked, and, in the history of science, one of the last topics upon which the scientific method was focused was man. Instruction in science, too, has concentrated on content rather than on the doer. Recent research, probing the creative and productive processes of scientists, may open the way for new approaches in science instruction. This will require not only insight into the creative process itself, but new concepts of the relationship between learning and creativity, and designs for teaching methods that will nurture creativity.

By new teaching approaches calling for exciting ventures into scientific frontiers, we should not only try to attract those with high productive and creative potentials to enter science for a challenging career, but also to inspire all students with the beginning of a lifelong interest in science. To do this, we may have to break away from some of our own teaching habits. For example, are we too often teaching only the "dead corpse of past knowledge" to our science students without giving it life or without giving them any chance to experience the living adventures and the excitement possible, especially at the frontiers, in both the search for and the production of new scientific insights?

The high focus on intelligence and scholarly abilities in our schools may have resulted in keeping creative talent from being more fully freed and developed. We should conceive of students as "thinkers" and producers and creators, rather than solely as learners or, in the worst extreme, recorders, memorizers, and "replay machines."

Remembering that science is essentially a human activity, science teachers should avoid creating the impression in any student that science is so highly verbal, so greatly formalized, and so formidable overall as to be frightening and repelling to newcomers.

Research is, of course, a prime example of creativity in science, but it is not the only activity of the creative person. In the following sections of this paper, I shall discuss the creative process and the creative person and indicate some of the ways in which instruction—particularly in science—can help to reveal and develop creativity.

THE CREATIVE PROCESS

We psychologists believe that all science students should have the experience, even to a small degree, of learning about and experiencing the creative process. Consequently, we have recommended that students go to art educators who try to teach creativity through art. However, science educators can outmode this recommendation by learning how to teach creativity *in* science and creativity *through* science. This requires an understanding of creativity and the creative process.

First, let us consider some definitions of creativity, particularly as it can be recognized in the scientific endeavor.

Jerome B. Wiesner in a paper on "Education for Creativity in the Sciences," published in a special issue of *Daedalus* on "Creativity and Learning," relates creativity to science as follows:

> The term "creativity" is principally used to mean activity resulting in contributions that have novelty and value in the intellectual sphere of human experience, including the sciences, as well as literature, music, and the visual arts. In all such contexts, "creativity" universally implies a departure from, and advance beyond, what is conventionally attainable. However, there is an important characteristic of creative contributions in science that is not significantly present in creative contributions in many other fields, namely, quantitatively definable logical relationships to preexisting scientific knowledge. Thus, although the emotional and intuitive appeal of a new idea or concept, or its esthetic richness, may make it "creative" in a philosophic or artistic sense, normally it must also meet the criterion of being logically relatable, in quantitative terms, to the body of science in order to be considered scientifically "productive." An idea must clearly follow from what is already known if it is to result in an enrichment of available scientific knowledge or of associated technologies. [26]

Philip H. Abelson, in the same issue of *Daedalus*, adds the element of judgment as an important part of creativity in science:

> The crucial element in creativity in science today is not dramatic illumination: it is judgment. When an experimental scientist seeks to be creative, he must make and implement a series of judgments. . . . To exert good judgment requires self-discipline, which, in turn, rests on adequate motivation.
>
> Motivation is essential to creativity; without it, even the best minds accomplish little. With adequate motivation comes the self-control necessary to draw on inner resources. Creative effort differs from most other activities in requiring unusual discipline. People in other walks of life may go for long periods without exercising much self-control. But a creative scientist must take himself in hand. The initiative must be his. No foreman can tell him how to think or what to do next. He has to do his own thinking and make his own judgments. Therefore he must organize himself and his activities. [1]

To Toynbee, creativity "is mankind's ultimate capital asset." [25] He also states that it is a most vital ingredient in the shaping of history, so much so that he warns America that "to give a fair chance to potential creativity is a matter of life and death for any society."

Brewster Ghiselin, editor of *The Creative Process* [5], has developed a checklist for the creative process, designed to tell to what degree a person's processes resemble those of creative persons as they do to their work. [6] He states the steps as stages, which with my modifications are as follows:

The first stage of the creative process is a stage of *puzzlement*, in which a person senses, at least vaguely, that there is something amiss or that things are fuzzy and not clear or understandable. Occasionally one may even sense more explicitly that a specific problem exists.

The second stage of the creative process is best described as one of *mental labor*. It entails something more than just preparation through rote memory or other methods of accumulation of knowledge. It is deeply involved mental work of a nature which enables one to move through the next two crucial stages of the process. A most significant part of this preparatory mental effort may be a seemingly fruitless struggle with the problem in some vague out-of-the-way part of the mind.

The third stage is one of quiescence of *incubation* or gestation. In this incubation stage some persons have been described as going into a psycho-social moratorium.

The fourth stage often found in a successfully continuing creative process is *illumination*—the insight, or "Eureka" stage.

The fifth stage entails further labor and deliberate effort in which *elaboration*, revision, and verification inputs and outputs are involved.

This kind of scheme is probably oversimplified, but it does represent some of the main features often reported by creatives and can be useful to teachers.

There is reason to think that much of the creative process is intuitive in nature and entails the work of the mind prior to the arising of its workings to the conscious level. This process is certainly also prior to formulation of the "stuff" of the mind in expressive form. It is very likely preconscious, nonverbal, or preverbal, and may involve a large sweeping, scanning, diffuse, free, deep, and powerful action of almost the whole mind, but not, of course, a slavish following and imitating of established patterns.

Both the input and the central processes may involve thinking aside, thinking at right angles to the usual scheme of thought, scanning and widely diffusing the attention, and gleaning on the periphery as well as centrally. An almost unfocused state of seeking "without any blinders" seems to be best at this early stage.

How the individual scientist receives information is important. This input process can be done more creatively or less creatively. How he handles the information internally—how he stores it and interweaves it internally with other stuff already present—can also be done more creatively or less creatively. So we can ask to what degree his reception is creative, to what degree his central processes are creative, and to what degree his mode and form of expressional output are creative. Shouldn't we be concerned about each of these processes, too, in our science students?

One writer has said that when you are reading and get a new idea (not directly from the book, but one which was sparked by your reading), you should set the book aside and pursue your new idea, instead of continuing to read. Have you ever tried reading for this completely different purpose of triggering new ideas, and do you think your students know how to do this as effectively as they potentially could? Have you asked them yet to try this type of reading? Or listening? Since an audience can listen and think much faster than speakers can talk, are there ways you can capitalize on this by agitating the imaginative thinking-while-listening processes of your students? Beware, though: what often happens may be the other extreme. Information is often presented in dull ways so that the readers and listeners become occupied with quite irrelevant and even unrealistic daydreaming, instead of having their productively creative thinking processes accelerated.[1]

KNOWLEDGE AND THE PRODUCTION OF NEW IDEAS

How does knowledge fit into the creative process? Is there any assurance—or even indication—that the sheer accumulation of knowledge in the early stage of the creative process will lead to fruitful incubation and inspiration, that is, to a successful total

[1] With a little research effort, I strongly suspect that we could demonstrate that a distinct difference in the amount and quality of thinking would occur if the same information were presented first in a formal, formidable, "awe-full" style (like gobbledegook or like much of current scientific literature) and then in a style designed to be as provocative as possible.

creative process? Will this sheer input ensure that a person will move successfully through the entire creative process? If not, then what is the role of knowledge or information? What information is needed? How should a student gain knowledge in order to more nearly ensure that both incubation and inspiration will successfully follow? Which is more important in creativity, knowledge or process?

People who possess approximately equal amounts of information in a field can differ greatly in creativeness. How a person receives and processes information may be as important, if not more important, than the information itself. The attitudes of a person about the information, what instructions he gets, the set of his mind, what clues he picks up while he goes about searching for information, the way he receives, stores, mixes, and blends new information with the already present inner resources can all be very important.

There is evidence that *how* a person receives information affects that person's creativeness. [11] If subjects are told to receive a given piece of information in a constructive way and are then faced with a situation in which they can use this information as an asset in solving problems creatively, they tend to do so. Another group, however, instructed to receive the same information with a critical and destructive attitude, will tend *not* to use the information when they encounter a situation in which it may be useful. Apparently, the second group's devaluation and discarding of the information at the first stage leads to ignoring the information at the second stage. We see that at the receiving stage, an openness, an unfocused set, and an attitude of constructive perception can be as important as how one stores and mixes the information received with the other material in the mind.

Hyman also comments on the enigmatic role of knowledge in relation to creativity. On the one hand, knowledge can be the stuff used in getting us to the fringe of what is known and also some of the stuff used in creating. On the other hand, it may have negative values, since it tends to bring past patterns to our minds and may thereby impose restrictions upon our thinking.

Admitting some oversimplification, we frequently assume that if students can learn and recall in verbal form all the knowledge prescribed, then all good things in life will almost automatically happen to them, and they will become highly creative and productive. So far the available evidence indicates that this assumption is not really justified. In our own studies, little or no relationship has usually been found between performance in the academic world and performance in the world of work.

There is much more to this problem of developing creative talents than merely making sure of a continuing, efficient flow of well-established scientific information into your libraries, into your texts, and into the minds of your science students. We need to learn how to teach students to become well versed in scientific knowledge without becoming inflexible and set in their thinking and attitudes. Shouldn't we try to discover which students learn new information with great awe and which ones use the same information mainly as a springboard enabling them to move ahead in what they are trying to do? And shouldn't we give all students both experiences so they will know these differences for themselves?

With knowledge accumulating so rapidly—especially in the science fields—the total problem of what to learn can become a most acute one. In fact, one must wonder to what degree we can be content with present content, and as a consequence, to what degree students should be learning to deal with changing knowledge. Learning, within all the artificial "props" and school requirements, is apparently a process that does not really transfer and therefore does not prepare students adequately to keep abreast on their own after their formal education is finished. Don't we therefore have a large responsibility to make students aware of this problem and to help them learn ways of keeping abreast with the knowledge explosion that will enable them to keep doing so on their own?

Students should have the experience of not only adding new knowledge to old, but also revising or replacing old knowledge in light of new evidence. If you give them this experience, their understanding of and interest in knowledge can increase, and they may become more active themselves in trying to improve and expand man's knowledge.

The research to date suggests, too, that the psychological processes of mastering known information are not highly overlapping with the psychological processes of producing new information. That is, gathering existing information and *reproducing* it are not the same process as *producing* new information. In addition, the characteristics of good learners of old knowledge do not overlap highly with the characteristics of good producers of new knowledge, so that the good scholar and the good researcher, especially the creatively productive researcher, are not necessarily the same person. In fact, to a considerable degree a different set of characteristics is needed to be a good producer than is needed to be merely a good reproducer.

It is said that authorities will be eager to talk about what they know in a field, but creatives will not care to dwell on what they know—they will be far more interested in thinking and talking about what they do not yet know. One of the characteristics of creatives is that they are continually striving for better and more comprehensive answers. Students who are full of challenges, who can produce a bombardment of questions about ideas, answers, grading procedures, and so on, may have good potential as effective scientists or other creatives.

To counterbalance any tendencies of magnifying what is known, we feel that more time and attention in classes and in texts should be spent on what is not yet known, on unsolved problems that present the greatest challenges for the current generation of science students.

One teacher suggests that every day we should spend some time on what is not known in a field (including unsolved problems) to keep some of the attention and awareness of students focused on the future. Don't we also have an obligation to give students experience with knowledge at its various stages of development, not with just the most well-defined and substantiated scientific knowledge? Shouldn't they have enough experience with how well founded each bit of scientific knowledge is so that they become able on their own to recognize this aspect of each portion of scientific knowledge that they encounter? And shouldn't they also have greater understanding of the difficulties involved in the production of one new insight or one new bit of knowledge, and, therefore, the miracle of its existence?

IDENTIFYING CREATIVES IN THE CLASSROOM

The classroom genius, identified solely by intelligence tests, is not the only type of genius. Only recently have such seemingly unmeasurable quantities as creativity been explored. Fluency of associations, expressions, and ideas; spontaneous and adaptive flexibility; penetration; originality; visualization; elaboration; foresight; and certain evaluation abilities—these and other talents are being probed by researchers. [15, 21]

When we compare creative and noncreative persons, we can recognize certain differences and take advantage of these differences to provide situations in which these creative traits can be displayed and strengthened. For example:

• *Creative persons are more self-sufficient, basing their behavior upon their own concept of themselves rather than depending upon close supervision and guidance from others.*

Are there times when you could let your students do most of the planning on their own and make their own decisions so that you could observe who has the least need of training and experience in self-guidance?

• *Creative persons are more independent in making judgments and are willing to stand alone against the group for the sake of accuracy in their reporting.*

Can you detect which students would stand their ground if challenged by classmates or even by you after they have given what seems to them an accurate observation or a correct response?

• *Creative persons are more self-assertive and dominant, more stable, more self-accepting, more aware of and open to their own impulses.*

Can you develop exercises in which students report their inner feelings and impulses and then see how well they can intuitively anticipate a correct course of action? For example, ask for hunches on which way the results will come out in a complex experiment previously unknown to them and then check accurately after doing the experiment to see whose hunches most easily forecast the outcomes of the experiment.

• *Creative persons are more progressive and radical than conservative; more courageous, adventurous, and otherwise more capable of taking greater risks backed by their own efforts in the hope for greater gains.*

Since original thinking can be contrary to currently accepted notions of what is common sense, such thinking may rarely find a ready-made acceptance. On a complex issue, try to see who takes a hopeful attitude and who would take the "can't doer" stand that things are in an impossible state of affairs and nothing can be done about them. Would you be willing to give special credit to students who manage to achieve a goal in the face of objections from fellow students, from the teacher, from the home, or from others in the society? Can you look for those students who have accomplished something worthy in spite of such opposition and difficulties?

• *Creative persons are more complex as persons and may stir up group sanctions against themselves as a result of their new ideas, which may be sensed by others as a threat to the status quo.*

Do you ever have idea-generating sessions to see who expresses (or generates) the most ideas, whose ideas elicit the strongest negative reactions from their classmates, and who tends to lead in expressing these strong negative reactions? Do you ever observe to see who uses what techniques to squelch or even kill the ideas of others? And who has the most courage to hold his ground, or even move ahead, instead of retreating or folding up under these attacks?

• *Creative persons are more resourceful.*

Can you set the stage to find out which students have this characteristic to the highest degree? Can you then find ways to encourage all of your students to be more resourceful and to develop this characteristic so that it will be more available when needed? For example, you can ask your students to do a task of a type which they have done before, but this time take away most of the facilities previously available to see who will be the most resourceful, either by finding substitutes for the missing facilities or even by somehow managing to accomplish the task without any of the usual facilities.

• *Creative persons are able to tolerate a great deal of ambiguity and can thus live for long periods of time with unsolved problems and with what others often may feel to be confusion.*

You may find that some students resist "closing up" or crystallizing things prematurely (jumping to conclusions), and display a strong need for arriving at ultimate solutions through their own efforts. Can you structure some classroom exercises geared to reward those who tolerate ambiguity, who keep the problem open and keep working on it with their own resources until they eventually, but not immediately, attain a more worthwhile basis for "closing up" the problem and reaching a solution?

• *Creative persons are more likely to give unexpected responses, to take new steps forward, to pioneer at the frontiers where trails do not yet exist—indeed, they are attracted to, rather than fearful of, pathfinding and trailblazing challenges, and like to give them their full attention and effort.*

Do you provide opportunities in your classes to develop these characteristics? If we can set the stage so that our students have a chance to toy with the unknown areas at the edge of a field of study, those who immediately become involved may include the more creative.

Motivational traits of creatives include a great involvement in their work, intellectual persistence and thoroughness, and a desire to manipulate and toy with ideas and to make theoretical contributions. They may have a need to improve upon currently accepted systems and thereby to gain greater mastery of a problem. They show a need for autonomy and independence and the right to make their own decisions. They also have a need for variety; they prefer complexity. They may seem almost insatiable in their desire to organize things their own way. Do you give students opportunities to use their own minds in these ways? And do you sometimes give them a chance to stretch the creative parts of their minds by exposing them to questions of great complexity and the potential challenges therein?

Students who are accustomed to learning slavishly and mastering ideas and things of the past might enjoy an assignment to identify tools, gadgets, or procedures which are working badly and to design better ones to replace them. They could also search for gadgets which work moderately well but could easily be improved with a little thoughtful modification.

Many creative scientists report that when they were in school, they learned more about the things which curiosity led them to study on their own than they did from either classroom work or assigned homework. Would you dare to give credit to students who have learned the most on their own in unassigned areas of learning? And would you even go so far as to commend and encourage your students for such incidental and even deliberate learning about things that are not part of your regular curriculum? Would students be in trouble if they became so deeply absorbed in their own areas of interest that they had no time left to do your assignments?

Curiosity about the unknown and the inadequately known can be expected from some creatives, whether encouraged or not. In school situations they show ability to sense ambiguities and to raise questions. Which of your students are most alert to sensing ambiguities in textbooks or in your presentations? Who asks the most unexpected or the most penetrating or the most revolutionary questions? Could you deliberately give your students work in class which will develop these sensing and questioning abilities?

If an idealistic worker or student under your jurisdiction suggested how your class program might function better, would you be inclined to react negatively and call him and his ideas subversive? Or would you be big enough to realize that he may be most loyal to both you and the program by using his creative thinking to try to help it become the best program possible?

Rapid returns in new ideas might be obtained merely by being more straightforward in giving instructions, stating that ideas are highly valued and needed. For example, in a manufacturing company that had not been thriving for several months, the president, after trying many things, finally used a direct approach and told his engineers that "what we need are patents and we cannot survive without them." In effect, his workers wondered why he had not told them this before, because they immediately started to produce patentable ideas. Perhaps you as a teacher should try this direct approach of giving your students clear and sincere instructions that you do want them to produce ideas, perhaps one a week. This simple, direct emphasis by itself might bring a larger improvement than anything else you could do to inspire students to develop their creativity.

There is evidence that creative processes can be used as one way of learning, and certain students can learn better through this creative kind of learning than by authoritarian instruction. Moreover, many types of information can be learned more economically by creative kinds of learning than by authoritarian kinds of learning. Individuals, too, differ in their styles of learning so that we need to help each student to learn by his most effective means.

We should be aware of, and emphasize, the fact that there is more than one type of high level talent: Top performance in frontier research work, for example, calls for a type of productive and creative thinking that is not usually required in scholarly "library" work focused on what man already knows.

FURTHER CLUES TO CREATIVE TEACHING

Four major avenues provide us with guideposts for creative teaching: (1) *products* of students and others, (2) *processes* in students (to see whether their creativeness can be increased), (3) *creative characteristics* of students, and (4) *varied environments* of students, especially the human environment as it affects creativity. And of course various combinations of these four approaches can be used. Some research studies have helped to identify these guideposts. A few can be mentioned here.

We have been involved in two distinctly different types of studies that pertain to learning, thinking, and other productive characteristics in students. The first study was a 1963 demonstration project, a dissertation by Hutchinson [10] modeled after our educational theory that different talent processes can be used to acquire subject matter, and the curriculum can be deliberately designed to cover simultaneously both a wide range of knowledge and a wide range of talents. This study involved a deliberate change in the way subject matter is presented and learned in the same classroom. In this study, a set of four classes was taught by a traditional method in which students *receive and reproduce* existing knowledge. Then a matched set of classes of students was taught by the same four teachers in a different way. They were considered to be thinkers, not merely learners, and were encouraged to use their productive thinking abilities on the subject matter to which they were being exposed. A different group of students emerged as the star performers when a change was made from considering students to be merely learners to seeing them as thinkers—that is, when the class was changed from a *receive-and-reproduce* to a *think-and-produce* situation.

The second study involved a naturalistic investigation in two different settings in NSF Summer Science Programs for High School Students. We have compared the characteristics needed to perform well in a typical classroom setting where existing knowledge is being learned and mastered, to those characteristics needed by another group of students to perform well in a research laboratory where new scientific knowledge is being produced. In both types of studies we discovered that different characteristics are often called for and different students tend to become the best performers as the nature of the activity or as the nature of the mode of learning is altered. In other words, different psychological processes are required in a biology course with classroom work only than in new research work in biology involving producing new scientific knowledge. Likewise, psychological processes used in laboratory work involving repeating someone else's experiments according to the lab manual (almost "by the numbers") are considerably different from those used in frontier research work.

In a personal communication, Gallagher of Illinois [3] made a suggestion to me, which I have used successfully numerous times. He has asked teachers to think about each of the specific environmental features that might affect creativity. His question, cleverly, was reversed: "How would you design a classroom or school program that would be most effective for hindering, stifling, or even killing creativity in your students?" After the teachers named numerous specific features which they felt would be effective in curtailing or blotting out creativity, one of them suddenly realized and volunteered that many of these negative features are already present in many of our classrooms. Have we somehow ignored creativity in designing our present classroom programs, or have we even gone further and allowed forces that might work against creativity to be strongly built into many of our programs?

Some evidence suggests that students have lost part of their questioning and curiosity ability prior to high school. Perhaps the loss begins just after they reach the stage where they can ask better questions than their teachers can answer. When we as teachers feel like giving an immediate, strong, and negative reaction to a student's question or comment, perhaps we should curtail our emotional response and postpone our reply until we have cooled off and examined what aroused our emotion. We should ask ourselves whether we might have been ready to stifle curiosity or kill an unexpected and perhaps creative response in our students.

Education should pay considerable attention to Richard Suchman's experiences in inquiry training. He has found that high school students have a greater need for such training than do second-graders—in fact, the second-graders are already better than the older students in their ability to ask questions (one verbal form of curiosity in action). Shouldn't remedial training be given to restore the questioning abilities that have somehow been partly lost in our high school youths? If suitable corrective steps can be found, then their questioning and curiosity abilities might continue to develop through school without setbacks. And shouldn't we be deeply concerned about the degree to which our students are or are not developing inquiring minds?

Requiring a student to tell at any and every time what he is doing may work against effective deeper processes, such as successful incubations (the third stage of the creative process). If a student intuitively senses potential complications from premature verbalizing and resists such requirements, or if he is somewhat incapable of verbalizing during his own incubations, he may find himself in conflict with his teacher or with school requirements. But you, as a science educator, must have more understanding so that his incubation may have a greater chance of moving ahead without setbacks to a full and successful completion. Will you be prepared to respond suitably if such an unexpected, though intuitive, conclusion to postpone verbalizing is reached?

If a student shows the creative characteristic of striving for better or more comprehensive answers than the text or teacher now has to offer, what will happen between the teacher and the student? Will the inquiring student encounter difficulties in your classes? Can you help him learn to live and deal successfully with such a potential conflict situation without losing some of his creativeness?

A handful of the pertinent research findings to date collectively suggest that *if a person has a truly creative idea, the more creative it is, the greater the probability that he and his idea are in trouble*—especially with those around him. At first he is the only one with this idea, so that he may feel pitted against the world. He may have to learn to live through lonely, troublesome periods. If one of your science students has a truly creative idea, would he be in trouble in your setting? Exceptionally good and big ideas might be rejected by other persons, while little ideas are relatively safe, since they merely move ahead by inches instead of by great strides and tend to call for only minor, trivial adjustments by others.

If one of your students should produce a highly creative idea, instead of an idea that just barely inches ahead, do you feel that you and your other students would understand and encourage him, or might you fail to understand and become impatient and uneasy and feel like "firing" him from your classroom?

The following points on how to teach for creativity are selected from a series on "Clues to Creative Teaching" which I wrote for *The Instructor* [16]. A teacher may want to select only one clue to try at a time while he otherwise continues his regular teaching methods. In this way he can more clearly feel the effects of the technique.

To encourage a variety of thinking, including speculating, you could ask for the students' thoughts and hunches in some area and then praise them for having ideas of their own. For example, you could ask a series of different types of questions such as the following: *What are all the possible uses* of a book (or a tin can)? *How could you change* this classroom to make it better? *How could you rearrange* the locations of the classrooms to make a different-shaped school building? *What are all the things that you would do if* you made an emergency, but safe, airplane landing in the winter, up in the snow-covered mountains? *What would happen if* all the sources of electricity suddenly stopped functioning and could not be repaired?

Other questions that you could use are: How can you add something to what already exists; or subdivide something; or substitute for something; or expand something; or redefine something so it could be put to other uses? How can you reverse something by flipping it over to see it from another viewpoint? What things could be put together to make a new combination? What are all the characteristics of something? What problems about something can you sense that other people usually miss? How can you keep thinking about something without making a premature judgment about it?

NEW APPROACHES IN SCIENCE EDUCATION

A study by Liam Hudson of Cambridge University in 1963 showed that students with higher scores on creative thinking tests tend to major not in the sciences but rather in the liberal arts. [9] Does this suggest that our science courses may be taught so as to repel, rather than attract, creative-thinking students? What revisions in established teaching habits are necessary to attract students with high productive and creative potentials and to utilize these abilities in the knowledge-acquiring process?

Various instructional media could be designed or modified to be facilitators of creativity in students. [23] Scientific information and instructional materials could often be deliberately put into a more provocative style of presentation. The challenge is to discover ways to change our materials and presentations to such a style that would stimulate maximum thinking. Perhaps another clue for us as teachers is to remove hindrances to creativity, and to *un*-train for noncreativity, as well as to train directly for creativity.

In our attempts to do new things in science education, we may have to guard against going off target to do something tangible instead of trying to stay on target to do something important—though more difficult. For example, if a student entered a theoretical idea in a Science Fair, he wouldn't have a gadget to show and might sometimes not have much chance in the competitive display (regardless of the fact that theoretical scientists are generally seen by their peers to make the greatest contributions to science). Could you devise programs where non-gadget ideas would be encouraged and judged fairly and rewarded for their merit?

A reorientation in the teaching of the scientific method seems warranted if we are to relate it to creativity. I. Gregory, in *Psychiatry: Biological and Social*, comments that

Research activities may be classified into a variety of types—The most fundamental distinction appears to be that between two major developmental phases through which the research process (but not necessarily individual research projects) tend to pass. These two phases have been termed: (1) exploratory, hypothesis-developing research, and (2) confirmatory, hypothesis-testing research. In any given project, these phases frequently overlap, but the conclusions resulting from exploratory studies claim far less than the conclusions resulting from confirmatory studies. Moreover, productive exploratory research appears largely related to inherent intellectual and personality characteristics, whereas, productive confirmatory research appears more closely related to training in appropriate scientific methodology. [7]

The last sentence of this passage suggests that education and training apparently contribute little to the selection and preparation of scientists to do effective exploratory research. What we are teaching as scientific method in our schools is concerned mainly with the usually less creative confirmatory phase of research. The emphasis on high verbalization and perfection of definition before one can start doing research may be one of the greatest deterrents to creative thinking.[2] Because the initial research experience seldom yields major contributions, it is desirable that graduate students in science have an opportunity to complete a third or fourth piece of research, but this is frequently not the case. From early in the educational process, therefore, greater stress should be put on participation in a series of research projects, with the result that students will gain greater insight not only into their research problem, but also into the heart of the scientific method.

The physicist P. W. Bridgman has commented that scientific method, insofar as it is a method, consists of no more or less than doing the utmost one can with one's mind. [2] Similarly, Donald Taylor has told the author (in a personal communication) that if you want to start thinking about a scientific problem, just start doing research and the thinking will follow.

Our preliminary evidence seems also to indicate that we should start much earlier than graduate school to introduce students into research activities. Very early in their school careers, we should have students sense problems on their own (even though, unknown to them, some of the problems may already have been solved), to make observations on these problems, to learn how to collect data, and in other ways to learn on their own, using

[2] For example, see "Letters" by Johan Bjorksten entitled "Criteria for Research Grants." *Science* 133: 1040; April 7, 1961, which indicates how research proposals for the research work by William Harvey, Albert von Haller, William Beaumont, A. L. Lavoisier, and Louis Pasteur might have been turned down by modern-day panels judging these applications by currently used criteria.

as much of their own internal resources as possible rather than relying mainly upon outside authorities.

According to widespread practice, junior high school students are presumably not ready to do research. But if you check for yourself, they are more ready than has been suspected. Certainly, in some summer science research programs senior high school students at the end of an initial research experience of two or three months, are writing very technical reports, more technical than you or I would understand unless we were specialists in the field. And some of them have actually submitted and have had their papers published in regular science journals in competition with senior scientists. One program director told us that about 25 percent of his high school science students are producing publishable material. Yet our regular science education programs almost deliberately keep people away from doing new research, usually for 16 or 17 academic years, even *though the students* are ready much earlier.

In NSF- and Air Force-supported projects, [20, 22] high school students were observed to be remarkably ready to participate in research work. They generally displayed fresh, eager, interested, active minds ready for new ventures into new areas of investigation. They were more exciting to have around research centers than were older, "more advanced" students from the college or graduate levels. As a result of their receptiveness, we wonder why, after a live research experience at the end of their 10th or 11th school year, they will probably have to wait until their 17th year for their second real experience in research work. As a sharp contrast, practically no one has advocated postponing participation for art students: From the beginning years, art students practice the skills and techniques they will use as productive artists.

For stocktaking purposes, we recommend a series of different ways to view educational programs. [24] A first perspective is to ask to what extent our educational programs are developing *all* of the nation's important human resources. A second is to view science education from world-of-work requirements—what scientists do on the job. A third concerns the degree to which educational programs are giving students greater self-understanding and self-awareness, especially about their own high-level talent profiles.

The last and main perspective advocates a three-dimensional model for viewing educational programs. We suspect that curriculum activities usually focus on two dimensions, namely, what the teacher does in terms of methods, instructional material, setting the stage, etc., and, second, what subject matter the teacher imparts to the students. We would change the emphasis on this second dimension to what the student learns and add a third dimension (also emphasizing the student rather than the instructor) pertaining to the psychological talent processes (thinking, learning, sensing, etc.) that occur and are experienced by and developed in the student as he is acquiring subject matter. Our proposed model might be simply stated as:

1. What the teacher does (mode of instruction)
2. What the student learns (curriculum content)
3. How the student learns (psychological talent processes)

If nothing else, a curriculum constructed along these lines will encourage a conception of the student as an active "thinker," rather than a passive recipient of stereotyped material that must be memorized and repeated at impersonal, periodic intervals. It should also prepare him to be more ready to move into the kinds of productive intellectual and non-intellectual activities needed in performing effectively as a full-fledged scientist. Besides geniuses in intelligence and geniuses in creativity there are other types of genius, too, arising from high-level talents in planning or in decision-making, in executive abilities, or in various communication abilities, and so forth.

By focusing more upon the work of scientists on the job, we can improve considerably upon old patterns in science education, rather than slavishly follow them with all their shortcomings. For example, grades in school are of disappointingly low value in predicting creative and productive performances in scientific work. In some studies grade-point averages have even had nearly zero forecasting validity. The shortage of good research scientists is so vital a problem today, and will continue to be in the future, that their recruiting should not be restricted on any basis such as the current methods of evaluation which exclude large numbers of potentially successful scientists. By and large, more creative and productive performances must be required in school activities and graded for creativeness and productiveness if grades are to have greater predictive value for the future career performance of the students.

Greater variety in education would result from greater concern with these several other kinds of talent. School might be more fascinating if students had a chance to try out all the "keys of their mind," all their talents in turn, while they were simultaneously acquiring subject matter. They *can* do both concurrently, but it may be necessary for a set of different teachers to play a wide range of keys in their combined set of teaching methods in order for students to experience a wide range of thinking processes while learning various subjects. By working simultaneously on both content and processes in students, we are also increasing our chances that transfer of training will occur. This spread or transfer effect can occur both in terms of the important thinking and learning processes (the talents) used, as well as in terms of content learned.

As we ponder this new approach, we wonder if one reason why our society does not give much moral and tangible support to education is that persons leave the academic world and find, to some extent, that the intellectual (i.e., learning and thinking) characteristics in which they are highly trained are not called for in the world of work as much as they expected. Instead, other intellectual characteristics in which they have had little training may be crucial attributes in their part of the world of work. Thus, education has a challenging new responsibility to help students exercise and develop all of the known thinking abilities as their minds feed upon, toy with, and otherwise process and utilize current knowledge.

The total scientific method has many self-correction features within it which enable the state of knowledge to be lifted to a higher level of perfection. If we can strengthen our whole scientific effort (including our science education) through these self-correction devices and improve current insights and practices, we likewise will be strengthening all that science underlies in our nation. We will be setting an example of self-correction for other fields to follow. Just as we argue for the importance of the general application of the self-correction features of science, likewise do we argue for the importance of creativity—not only in science but in all fields—as a way to strengthen and perfect our way of life.[3]

[3] See Gardner, John. *Self-Renewal: The Individual and the Innovative Society*. Harper & Row, Publishers, New York. 1963. See particularly Chapter 4.

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